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Compressors and Pumps

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I. INTRODUCTION

Compressors and pumps are used to move materials for a large variety of purposes. Applications for these machines are in industries such as steel, petroleum, chemicals, mining, food, gas production and storage, and energy conversion (refrigeration). Their shutdown means lost production. Compressors and pumps transfer gases, liquids, or sometimes slurries of liquid/solid mixtures. Lubricants in these applications lubricate moving parts such as bearings and gears, provide a liquid seal, and remove heat. These can be a difficult tasks, as lubricants often operate in hostile environments.

There are many reasons for using a synthetic lubricant in almost any type of machine. An individual synthetic may have specific advantages, but none is superior in all respects. Typically compressor and/or pump applications have some characteristic or group of desirable properties that contributes to a synthetic's performance advantages over mineral oils. Synthetic fluids can operate at higher temperatures, exhibit better low temperature fluidity and pour points, and are less volatile than equiviscous mineral oil counterparts.

Similarities exist between the design of compressors and the design of pumps. Two classifications for compressor are dynamic and positive-displacement. Dynamic machines include centrifugal compressors and axial compressors. These types of compressor develop pressure by the action of a rotating blade, which imparts velocity and pressure to the flowing medium. Examples of positive-displacement compressors include reciprocating, rotary screw, rotary vane, lobe, and scroll. Positive-displacement compressors confine successive volumes of gas within a closed space and elevate them to a higher pressure. Vacuum pumps are compressors that operate with

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a suction pressure at a vacuum. Classifications for liquid pumps are similar to compressors (e.g., centrifugal and positive-displacement). The latter includes vane, screw, reciprocating, gear, and lobe.

II. COMPRESSORS

A detailed discussion of compressors is beyond the scope of this chapter but is available [1,2]. A brief description of these machines and their lubrication requirements helps to provide an understanding of how synthetic lubricants improve their performance. Examples of these compressors appear in Fig. 1.

A. Dynamic Compressors

Dynamic compressors handle significant flows at relatively high speeds. Multistage compressors are required for higher pressures. These machines are usually driven by a speed-increasing gear. The lubricant reduces friction and prevents wear in bearings and gears. Oil is not meant to pass into the gas stream. Various methods of shaft sealing are used to accommodate the variety of gases and applications. These include labyrinths, carbon rings, contact seals, and bushings. The lubricant may act as a sealing fluid or otherwise aid in the operation of these seals (i.e., hydraulic action). Small amounts of lubricant may enter the gas stream through seal leakage. Conversely, gas may enter into the lubricant system. In some cases the gas provides a positive pressure to

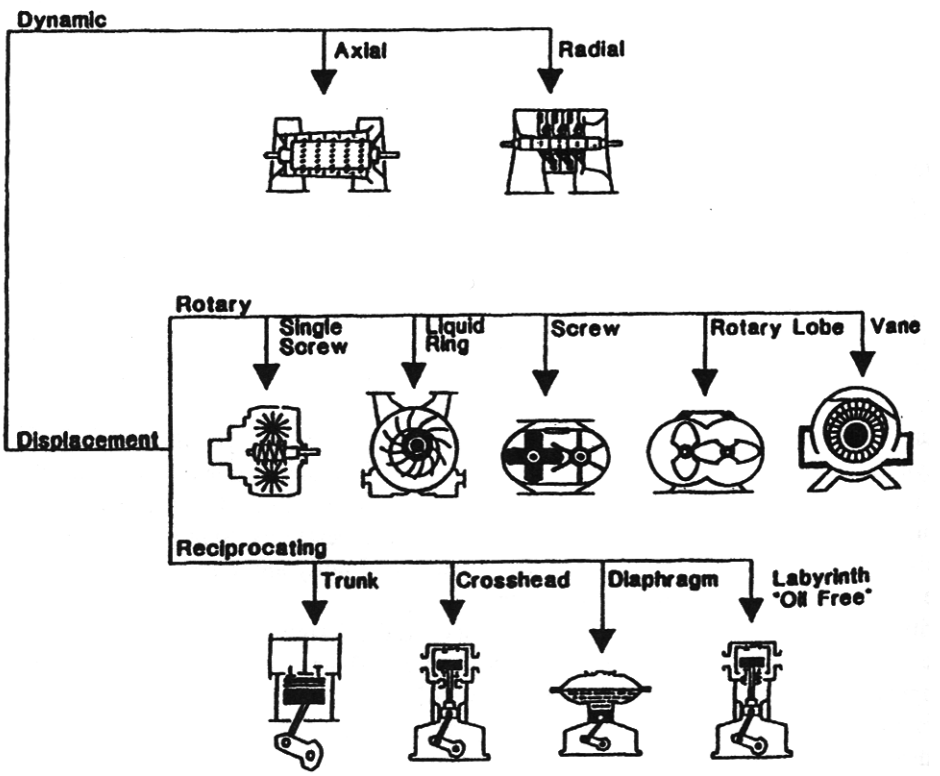

Figure 1 Various compressor types.

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the lubricant reservoir to prevent leakage of air into the system (as with refrigeration and some chemical applications).

B. Positive-Displacement Compressors

1. Reciprocating Compressors

There are several types of reciprocating compressor. Lubrication points include cylinders, valves, pistons, piston rings, crankshafts, connecting rods, main and crank pin bearings, and other associated parts. Double-acting machines use crossheads and crosshead guides with connecting pins to join the crosshead to connecting rods. Most single-acting compressors use connecting rods attached directly to the pistons with wrist pins or piston pins. "Oil-free" machines do not require lubrication in the compression area.

Cylinder lubrication is applied to cylinder parts, pistons, rings, valves, and rod packings. Crankcase parts include main and crank pin, crosshead (or wrist pin) bearings, and crossheads and crosshead guides. Additionally, the lubricant may help the efficiency of seals and minimize their wear. The crankcase on a reciprocating compressor may either be open to the cylinder (as in many vertical, V-type, and radial compressors) or sealed from the cylinder by a bulkhead and exposed to air (horizontal compressors). Bearing and other crankcase components require relatively large amounts of lubricant, which is usually supplied from the crankcase. Supply methods include "splash" (utilizing dippers in the oil), "flooded" (devices to lift the oil such as disks, screws, grooves, or oil ring gears), and "forced-feed" systems.

Cylinder lubricant may be "splashed" from the crankcase or "force-fed" from either the crankcase or a separate reservoir. Ideally, the amount of lubricant used is the minimum needed to provide a strong lubricant film (to minimize wear and friction, to seal piston rings, valves, and rod packings), remove heat, and prevent corrosion.

A machine with the crankcase open to the cylinder may experience gas leaks past the oil control rings and into the oil. In systems in which the crankcase is not open to the cylinder (i.e., the oil is fed to the cylinder walls and piston rod packings with a force-feed lubrication system) essentially all the oil fed to the cylinder eventually leaves the compressor with the gas.

2. Rotary Screw Compressors

Screw compressors [3] are constant volume devices having a built-in compression ratio. Compression in the single-stage, double-helical type occurs through the meshing of two rotors in a one-piece, dual-bore cylinder. The cylinder has air inlet passages, oil injection, a compression area, and discharge ports. Rotors are designated as male, with helical lobes, and female, with corresponding helical grooves. In oil-flooded machines, the lubricant is injected into the compression area, affording sealing via an oil film between the intermeshing screws, and removal of the heat of compression. Oil separators are used to remove the oil from the discharge gas. "Dry screw" machines utilize timing gears to position the screws so that no internal lubrication is required.

Liquid-injected, single-screw compressors are constant volume, variable pressure machines. Compression results from the intermeshing of a single screw with one or two gate rotors. The screw and casing combine to act as a cylinder. The gate rotor or rotors act as a piston. The screw also provides the action of a rotary valve, the screw and gate act as a suction valve, and the screw and casing (port) serve as a discharge valve. There is a relatively low amount of friction between the screw and gate, as nearly all the compression is supplied by the screw. Bearings may be lubricated by grease or fluid, depending on design.

3. Other Rotary Compressors

There are two common types of small-vane compressor: fixed and rotating. Both types provide positive-displacement, nonreversing compression. The fixed-vane type uses a ring or roller,

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which rotates around an eccentric shaft. A single vane is mounted in a nonrotating cylinder housing. The rotating-vane compressor has a rotor concentric with the shaft and off-center with respect to the cylinder housing. The rotor is equipped with radially sliding vanes, which are forced against the cylinder walls by centrifugal force. Gas is trapped between the vanes and wall, where a reduction in volume serves to compress it.

The lubricant in rotary vane compressors helps to provide a seal between the sliding vanes and the cylinder (or ring) wall. Larger systems may use oil pumps. Adequate lubrication should be provided to the vanes, vane slots, bearings, and seal faces. The oil to the cylinders may be supplied from the bearing lubricant discharge. The lubricant also prevents gas leakage in rotating shaft seals.

The basic compression unit in a scroll compressor is a set of two scrolls, one fixed and the other moving in a controlled orbit around a fixed point. Areas of lubrication include a short throw crank mechanism, bearings, and the scroll tip. Sealing is achieved through very accurate machining, proper balancing of pressures between scrolls, linkage mechanisms, and sometimes a sealing element at the tip of the involute.

Other types of rotary compressor include the lobe and liquid piston or liquid ring, which require no internal lubrication.

C. Compressor Applications for Synthetic Lubricants

1. Air Compressors

The major reason for selection of synthetic oils for air compressors is the stability of these products in the presence of air and moisture. Air contains about 21% oxygen, which reacts with hydrocarbon oils (oxidation) to form organic acids, carbon oxides, varnishes, sludge, and hard, carbonlike deposits. Water vapor can condense as the compressed air is cooled. This water may cause corrosion, or it may solubilize or form emulsions, events that not only interfere with compressor lubrication but promote more rapid deterioration of the oil. These undesirable reactions are catalyzed by certain metals such as iron and copper. The acids and sludge formed promote additional rapid deterioration of the oil [4].

Other considerations for selecting a synthetic lubricant are safety, reduced maintenance, and the potential to reduce energy requirements. Each type of compressor can take advantage of these benefits.

Reciprocating Air Compressors. Conventional mineral oils produce carbonaceous deposits on valves, heads, discharge ports, and piping. The safety aspects of an air compressor lubricant are major areas of concern [5]. Explosions and fires in the compressor and piping of oil-lubricated air compressors have occurred.

The following explanations for explosions and fires associated with the use of air compressors were developed over the past 50 years, but remain essentially unchanged [6], The majority of these occurrences are due to the presence of oxidized oil residuals (as carbon–oxygen complexes) on compressor discharge components and in the piping. The deposit continues to oxidize, in the presence of air and iron oxides, to eventually produce enough heat to ignite [7]. The temperature and oxygen partial pressure are also key factors. Fires and explosions are more common when oxidation of carbon and oily deposits occurs at temperatures above 300°F (149°C) and pressures above 100 psig (68 kPa) [8]. Deposits on discharge valves can lead to recompression of the gas due to valve sticking. This, in turn, can generate excessive discharge temperatures. Oil decomposition products in intercoolers and aftercoolers reduce the efficiency of these components.

Low volatility reduces the chance of a vapor fire (and resulting explosion, if excessive oil is present) [9]. The ignition source is usually related to carbon deposits or valve failure. The low

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carbon-forming tendencies of many synthetics as well as their higher flash, fire, and autoignition temperatures reduce this hazard.

Figure 2 illustrates higher autoignition temperatures for synthetic fluids at elevated air pressures. This information depicts common values for new, formulated compressor oils. Deterioration (through oxidation) will lower the autoignition temperature as exemplified by the lubricants containing iron oxides [10]. The discharge temperatures are for reciprocating compressors with inlet temperatures of 21°X (70°F) to all stages. Actual discharge temperatures will vary with cylinder size, degree of cylinder cooling, compression ratio, rpm, and other design variables [11].

Discharge temperatures for these reciprocating air compressors can easily reach 230°C (450°F), which is near the reduced autoignition of mineral oils at 135 psi (31 kPa) [12]. Excessive oil accumulation in the air system can propagate a fire. The special case of detonation, caused by the development and propagation of shock waves, is attributed to this type of fire. A simplified explanation follows. As the fuel burns, hot vapors evolve and expand, and pressure waves push into the unburned gas. These waves cause the unburned gas to develop extreme pressures and heat. The flame that follows results in an explosion in the piping, coolers, or receiver.

Phosphate Esters. Phosphate esters were originally selected for their fire-resistant nature [13]. Problems can occur when the lubricant degrades to form by-products that are aggressive toward paints and elastomers in older machines. Higher feed rates than those used with mineral oils may be required, and there can be problems with close tolerance lubrication between aluminum and cast iron cylinders. The high phosphorus content in these products can cause disposal problems. Even with these problems, phosphate esters continue to be used in high pressure multistage machines and other selected applications [14].

Fires and explosions can occur even with the use of fire-resistant synthetic oils such as phosphate esters if the lubricants are allowed to accumulate in the air system [15]. Lower feed

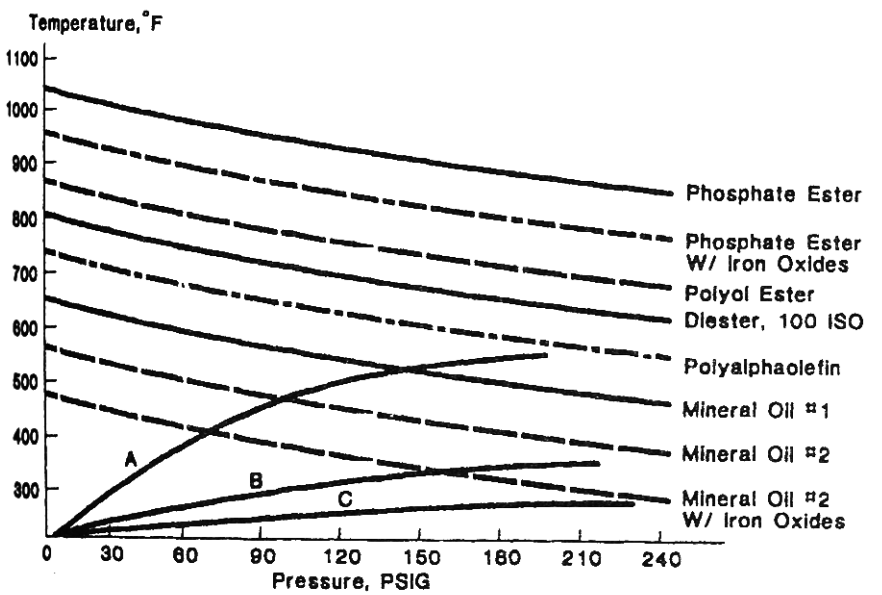

Figure 2 Autoignition of synthetic and mineral oils compared to discharge pressures and temperatures: A, single stage; B, two stage; C three stage.

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rates to compressor cylinders and oil/air separation equipment may be required to reduce this hazard. Devices have been developed to deliver smaller and more accurate amounts of lubricants [7].

Di-, Tri-, and Tetraesters and Polyol Esters. Compared to equiviscous mineral oils, these ester fluids have low vapor pressures at elevated temperatures. This property, good oxidative stability, in combination with an affinity to metal surfaces, makes it possible to use lower amounts of ester-type synthetics for cylinder lubrication. The feed rate for diester can be lowered to 50–65% of that used for a conventional mineral oil [8,16]. Polyol esters with low volatility, excellent stability, and high viscosity indices allow a feed rate of about 25% of a mineral oil. The actual feed rate will depend on the machine design and the specific ester's properties. The lower carbon-forming tendency of esters helps to keep discharge valves, cylinder walls, intercoolers, aftercoolers, and piping clean. This reduces the fuel/ignition source for fires. Another obvious advantage of reduced feed rates to compressor cylinders is the reduction in lubricant usage.

The cleanliness and good solvent action of the esters help to prolong the maintenance intervals of piston rings and valves. There have been several documented cases of maintenance intervals of two to four times the typical experience with mineral oils [8,17,18]. At least one investigator reported superior results with diesters as opposed to triesters (trimellitate) [19].

There have been many commercial claims that synthetic lubricants are more efficient and afford lower energy consumption than petroleum oils. This advantage has been attributed to the low coefficient of friction of esters, viscosity stability, and cleanliness. One study showed an average savings of 6.6% in kilowatt-hours consumed for a group of 23 reciprocating compressors ranging in size from 25 to 100 hp [20].

Polyalkylene Glycols (PAG). Polyalkylene glycols are not generally accepted as lubricants for air compressor applications. This is due to their relatively poor volatility, their tendency to form volatile decomposition products, and their poor compatibility with mineral oils. Blends of polyglycols and esters overcome these difficulties [21].

Polyalphaolefins (PAO). Formulated to have low volatility and low carbon-forming tendency, these products offer cleaner operation and reduction of fires in critical installations. Performance in a 120 hp two-stage reciprocating compressor operating at a discharge temperature of 392°F (200°C) and pressure of 100 psi (68 kPa) was still good after 16,000 hours of operation [22]. Other fully formulated PAO-based lubricants have surpassed the requirements of the ISO DP 6521 specifications [21]. PAOs have been blended with esters to improve their solvency and with oil-soluble silicones to reduce cylinder feed rates [7]. When deposits are formed, they are either very sticky (polymers) or hard varnishes (as with paraffinic oils). Another benefit of PAO-based lubricants is their compatibility with elastomers and paints found in older machines, which are designed for use with mineral oils.

Other Types. Other types of synthetic oil have been used for reciprocating air compressor applications. Fluorosilicone lubricants have been shown to reduce or eliminate air compressor explosions. Their high cost is offset by reduction in feed rates to 5% of that needed with mineral oils [23]. These oils have good lubricity with steel but may cause seizure with aluminum.

Rotary Screw Air Compressors. The lubricant in a rotary screw air compressor is circulated through a system that includes injection into the rotors. This design exposes the lubricant to high shear conditions. The oil also sees discharge conditions of high temperature, high moisture, high oxygen concentrations and metal catalysts. Both thin-film and bulk oxidation conditions exist. The presence of moisture promotes hydrolysis and may promote the catalytic action of metals. Thermal stability is important because the lubricant is exposed to the heat of compression. Conventional mineral oils deteriorate in a relatively short time under these conditions.

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Table 1 Properties of Rotary Screw Air Compressor Lubricants[a]

Property	Diester	Polyol ester	Polyglycol and ester	PAO	Silicone
Oxidation resistance	G	E	V	V	E
Flash point	VG	E	V	V	E
Pour point	VG	E	G	V	E
Volatility	VG	E	G	V	V
Lubricity	G	V	V	G	F
Demulsibility	G	G	P	E	E
Nonfoaming	VG	V	V	V	G
Rust and corrosion inhibited	G	G	G	V	F
Hydrolytic stability	G[b]	G[b]	G	E	E
Nontoxic	G	G	G	E	G[c]
Material compatibility	F[d]	F[d]	F[e]	E	E[f]

[a] P, poor; F, fair; G, good; VG, very good; E, excellent.
[b] Requires special additives.
[c] Chlorinated additives.
[d] Swells certain elastomers and may dissolve plastics.
[e] Not compatible with certain plastics.
[f] Silicone lost through separators may cause problems in painting operations.

Table 1 lists the desirable and critical characteristics for these lubricants [24,25]. Most synthetic lubricants listed will provide drain intervals of 8000 hours when operated in a normal environment and with discharge temperatures up to 180°F (or 90°C) and pressures below 68 kPa (100 psig). The different classes are used mainly in response to concerns with material compatibility, volatility, and operating life at higher temperatures or in high humidity.

Figure 3 shows the effect of high discharge temperatures for various synthetic lubricants.

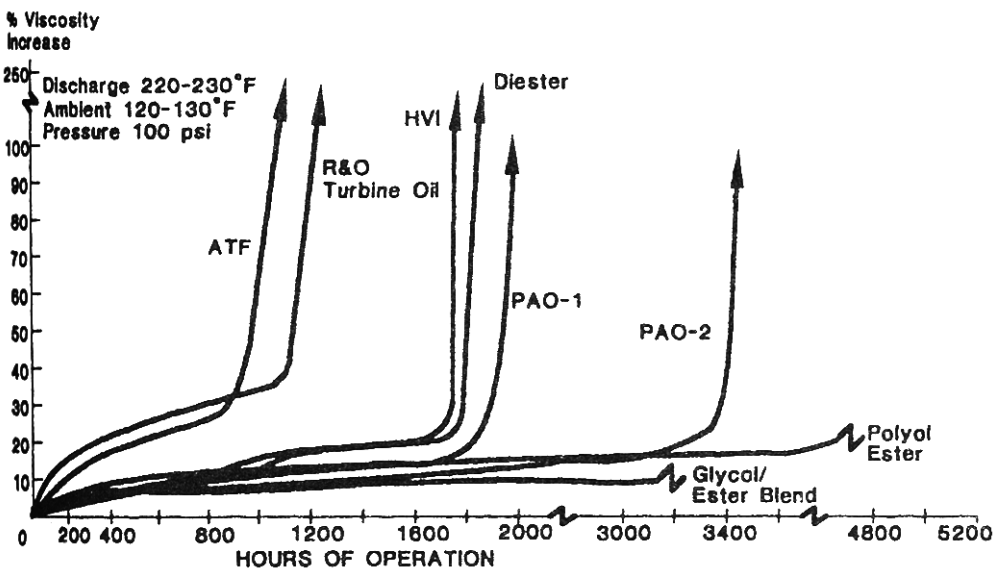

Figure 3 High temperature compressor test results.

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Most of these tests were conducted by a major compressor manufacturer in a 25 hp compressor operating with discharge temperatures of 220–230°F (104–110°C) and were reported in earlier literature [24–28]. The expected life of these lubricants at standard temperatures of 180–190°F (or about 85°C) is about four times that shown for the elevated temperature.

Energy savings are possible with synthetic lubricants. Conversations with original equipment manufacturers suggest the penalties attributed to using an unstable oils (Table 2). Careful selection of a synthetic lubricant will prevent these penalties in a properly maintained compressor. Most of these fluids can reduce or eliminate separator blockage and varnish formation. Heavy varnish increases energy consumption and can restrict rotor movement. The result can be air-end failures through excessive wear of rotors and bearings. A stable viscosity and good lubricity can reduce friction and increase efficiency. Viscosity stability and cleanliness can improve oil-side heat transfer. Some of the synthetics have higher thermal conductivity, which can improve heat transfer.

Diester and Triester Lubricants. Rotary screw air compressor lubricants based on di- and triesters offer the advantages of natural detergency and of not producing insoluble varnishes or heavy polymers. Detergency does not always end problems with separator blockage, however. One study showed that coalescer blockage with a diester was only slightly better than the performance of a mineral oil and significantly worse than a PAO compressor oil [29]. Esters dissolve varnishes left over from mineral oils and thus can improve the efficiency of a dirty machine (see above).

A study of 11 machines (40–300 hp) using diester lubricant showed that rotary screw compressors may benefit from reduced energy requirements averaging 9.3% (kilowatt-hours consumed) [20]. The study attributed energy saving to "friction reducing."

Esters, depending on the type (e.g., adipate, phthalate, trimellitate), usually increase in organic acid level and viscosity change during extended use at higher air compressor discharge temperatures (>210°F). This could lead to mechanical failures or corrosion [19,24,25]. Both base fluid and additives must be carefully selected to avoid these problems.

Diesters have a wide range of viscosity indices, depending on type and initial viscosity grade. They do not always meet rotary screw compressor manufacturer minimum viscosity index requirements (usually at least 90). A viscosity requirement at 210°F (or 100°C) is sometimes specified by the original equipment manufacturer (OEM). Diesters that have poor viscosity indices may have too high a low temperature viscosity for cold starting conditions. An adipate-type diester (or a blend) meets both requirements.

Polyol Esters. Polyol esters have not been used extensively for rotary screw air compressors. This is most likely due to their higher cost. These fluids have good oxidative and thermal stability [25]. Earlier formulations were limited by the availability of additives that would enhance the performance of these fluids. Long-term operation in rotary screw compressors at higher temperatures requires antioxidants and rust and corrosion inhibitors that are not volatile and do not themselves deplete too rapidly. Newly developed additives and increased availability of these fluids (some improved) should result in their increased use. The polyol esters have low

Table 2 Efficiency Loss in Rotary Screw Compressors

Problem	Penalty (%)
Viscosity increase or air-end varnish	3–5
Blocked air/oil separator, P + 10 psi	3–5
Excessive discharge temperature 18°F (10°C)	1–3

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volatility for a given viscosity grade. This helps to limit their consumption through the use of high efficiency oil separators. They have excellent lubricity (elastohydrodynamic), viscosity indices, and low temperature properties. Many of these fluids are biodegradable, an important factor considering that water containing some lubricant is drained from aftercoolers and receivers.

Polyalkylene Glycols. Polypropylene glycols blended with polyol esters provide long life in compressors with discharge temperatures up to 230°F (110°C) [26]. Polypropylene glycols by themselves have deficiencies. They tend to wet metal poorly, which can lead to rust formation in humid conditions. The ester is added to compensate for this deficiency. Polypropylene glycol has excellent hydrolytic stability and less water absorption than polyglycols of other types. Good vapor pressure characteristics are achieved with the higher viscosity fluid chosen for the blend (1200 molecular weight). Like the esters, the polyglycol/ester blend was reported to remain clean upon failure, producing "volatile components rather than cross-linking to viscous gums."

Phosphate Esters. Phosphate esters, except as additives, are not normally used in rotary screw compressors because of their rapid breakdown and formation of acids. The exception is critical applications that require the use of a "fire-safe" lubricant. In these instances the phosphate ester must be changed more frequently than other types of synthetic, usually every 500–1000 hours. The alternative is an "oil-free" compressor, where the phosphate ester may be used in anticipation of seal leakage.

Polyalphaolefins. PAO-based synthetic hydrocarbon oils have been used extensively for rotary screw compressors. They are often preferred over esters for use in standard 100 psi (68 kPa), 180°F (or 90°C) applications. The PAOs have excellent hydrolytic stability as well as compatibility, not only with rubber and plastic materials in the compressor, but also in the compressed air system [27]. They are also compatible with mineral oils and common additives. These features make compressor conversions from mineral oils simple and help to prevent problems with materials and equipment used in the compressed air system. The PAOs have very little effect on swelling of rubber or elastomers. It is very common to add ester to increase seal swell and to help solubilize additives and contaminants.

The PAO-based compressor oils have longer drain intervals (ca. 30%) than do diesters. Their low water absorption and rapid water separation result in improved rust and corrosion protection and facilitate the drainage of water from the oil reservoir. The PAOs' high viscosity index and low volatility allow the use of lower viscosity grades. This advantage, combined with excellent low temperature fluidity, reduces power consumption during start-up in cold environments.

PAO-based air compressor formulations that meet U.S. Department of Agriculture and Food and Drug Administration requirements for incidental food contact [30] are available. It is not clear how these lubricants will be eventually treated in Great Britain, where white mineral oils have been eliminated for this use [31]. The PAOs are not considered mineral oils and thus have not been banned for use with food by the British government. Most other areas of the world accept the U.S. regulations, especially for food imports. These lubricants are recommended for drain intervals of 4000 hours for standard applications [27].

Dimethyl silicone based fluids have an excellent viscosity index, as well as thermal, oxidative, and hydrolytic stability. Additives improve their otherwise poor lubricity with metals. A specially formulated dimethyl silicone rotary screw air compressor lubricant has been marketed since the 1970s [24]. Several compressors have been in operation for 40,000 hours. In most cases the results have been favorable [27]. Maintenance of the air/oil separator is critical because excessive oil carryover is expensive. In some cases (e.g., painting operations), the dimethyl silicone can deposit on production parts and cause manufacturing problems.

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Rotary Vane Air Compressors. Flooded rotary vane compressors benefit from the same synthetic lubricant properties described for rotary-screw compressor oils (see above). Many of these machines use a higher viscosity grade than the screw. An ISO 100 blend of PAO and phthalate esters was examined in two small (5.5 and 7.5 hp) air-cooled machines [32]. Severe test conditions were used: high temperature (140°C), high moisture, oxidants present, stop-and-go operation, and caustic environment. The results were determined to be favorable after 3000–3500 hours of operation as judged by relatively unchanged viscosity and acid number. The latter was considered important for maintaining a constant seal for stable air pressure. Oil consumption in a corona discharge process was exceptionally low, and as a result, the lubricant had no detrimental effect on ozone synthesis.

Diester compressor oils are commonly used in vane compressors. The natural detergent action of these fluid helps to prevent sticking caused by deposits in the rotor slots of sliding vane machines. Higher viscosity polyol esters should be particularly useful in machines operating with high discharge temperatures. Water-cooled machines of some types have discharge temperatures above 325°F (163°C). Some vane machines are equipped with plastic or composite vanes. The manufacture should be consulted as to the compatibility of these materials with esters. (Most are compatible.)

Centrifugal and "Oil-Free" Compressors. Synthetic lubricants provide a wide operating temperature range, better heat transfer, lower energy requirements, and reduced hazard (if seal leakage occurs).

Polyol esters are used for service in lobe compressors where high temperatures occur. One case involved the use of the lobe compressor as a blower for 600°F (315°C) air [27]. The polyol ester reduced bearing deposits (and failures), provided adequate viscosity for lubrication, and provided more efficient heat removal.

The mixing of PAOs with mineral acids results in, at most, very low exotherms. This effect, which is due to the saturated hydrocarbon structure of these polymers, makes the use of specially formulated PAO air compressor lubricants permissible in chemical plant operations where leakage through seals could result in exothermic reactions. One such case is in ammunition plants where concentrated nitric and sulfuric acids are used.

2. Gas Compressors

The lubrication of gas compressors encompasses many different types of gas, which can be categorized as inert, highly soluble, or reactive. The International Standards Organization has suggested further classifications under ISO DP 6743/3 B as shown in Table 3. It is recommended that these classifications be used for reference only and that the lubricant supplier and the equipment builder be consulted. In some cases these gases are divided into categories that relate to their industrial uses (oil refinery, chemical, halogen, polymer, landfill, etc.) [33]. The use of synthetic lubricants in these varied applications requires a variation of the ISO method of categorization. The type of gas (hydrocarbon, carbon dioxide, etc.), the functionality of the lubricant, and the performance of the compressor must all be considered.

There are three distinct areas of concern in gas applications: solubility, reactivity, and the effect of the lubricant as a contaminant in the compressed gas. The first two affect the compressor performance and the latter the gas application.

The solubility of a gas in the lubricant is a major concern. Excessive dilution may cause a reduction in viscosity and a loss of film thickness of the lubricant. The lubricant can be washed off wear surfaces by liquid components of the gas. Additional problems can occur when there is a reduction of pressure, followed by degassing (foaming, cavitation, loss of lubricant film).

The solubility of the lubricant in the gas can result in loss of lubricant by absorption of the

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Table 3 Draft ISO DP 6743/3 B Gas Compressor Lubricants

Symbol	Application	Application example	Lubricant type
DGA	Inert gas	<1500 psi Nitrogen Hydrogen Ammonia Carbon dioxide Argon All pressures Helium Sulfur dioxide Hydrogen sulfide <150 psi Carbon monoxide	Mineral oil or synthetic
DGB	Inert gas, moisture	As for DGA	As for DGA plus additives
DGC	High solubility	Hydrocarbons >1500 psi Carbon dioxide Ammonia	Synthetic
DGD	Chemical reaction	Hydrogen chloride Chlorine Oxygen >150 psi Carbon monoxide	Nonhydrocarbon fluids
DGE	Dry inert/reducing gas	Nitrogen Hydrogen 1500 psi argon	Synthetic

lubricant into the gas phase [34]. This can result in high lubricant feed rates and a source of contamination to the gas.

Reactions of the gas with the lubricant can result in premature failure of the compressor or, in more severe cases, fires and explosions. The lubricant or additives may react with or inhibit catalysts, cause mechanical problems in the application (valves etc.), or plug areas of gas flow.

Hydrocarbon Gas Applications. Hydrocarbon gases are encountered in the collection and transmission of natural gas, in vapor recovery, in landfill gas compression, and in the chemical industry. Synthetic oils are selected for their unique viscosity–temperature relationships or for their resistance to dilution by hydrocarbons.

Compressed natural gas and other hydrocarbon gases are used to fuel gas turbines. The compressor supplies the gas at the flow rate and pressure needed for continuous operation of the turbine. Petroleum-based lubricants carried in the gas may produce carbonaceous deposits in the gas inlet nozzles of the turbine, restricting flow and causing flameout.

Hydrocarbon gases are often the feedstock for a chemical process. Examples include the manufacture of polyethylene and polypropylene. Synthetic oils are often used for these applications because they do not react with or inhibit the catalysts.

Reciprocating Compressor Applications. For pressures below 1000 psig, ISO 100–150 mineral oils may be used. Problems occur when the gas is wet or at increased pressures. The

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addition of fatty oils is common. These additives, which are difficult to pump at low temperatures, can cause damage to discharge valves, accumulate in aftercoolers and piping, and emulsify with water. Detergent-type heavy-duty engine oils have been used in sour gas (H_2S) applications.

High pressure reciprocating compressors (5000 psig) are used to reinject natural gas into crude. Four basic problems have been identified [34]:

1. Loss of lubricant viscosity.
2. Increased cylinder wear rate because lubricant was washed off surfaces by liquid components in the gas.
3. Loss of lubricant to the high pressure gas stream. This resulted in feed rates to rod packings of 10 times normal rates, or up to a barrel of lubricant per day per compressor.
4. Reaction of additives with well-bore fluids, leading to permanent impairment to the well and reduced gas injection rates.

The study showed that the use of an ISO 200 polyglycol would solve all these problems. The higher viscosity index of the polyglycol resulted in a higher initial viscosity (undiluted) at compressor discharge temperatures. Resistance to dilution by hydrocarbon gases resulted in a diluted viscosity in the cylinder of about twice that of the diluted ISO 680 mineral oil based cylinder lubricant. It was shown that the polyglycol did not adsorb in the gas phase, while the mineral oil is nearly completely adsorbed. Field trails showed a 20-fold increase in the life of pressure packings and a reduction in overhaul maintenance from eight times per year to once per year.

High feed rates with mineral oils can cause problems in natural gas pipeline booster compressors. Excessive oil downstream reduces the volume within the pipeline and leads to a significant reduction in pipeline efficiency. Silicone "semisynthetic" blends with white oils (sometimes PAOs) are used in combination with microlubrication hardware to lower cylinder feed rates as much as 95% from that with mineral oils [35–37]. These systems have been in operation in more than 230 natural gas pipeline booster compressors in the United States since 1981. The reduced feed rates and the use of the synthetic oil have resulted in longer cylinder ring life. One report showed no measurable wear after 2 years. Discharge valve life is improved because there is a decrease in carbon buildup. The lower feed rates from microlubrication systems result in lower oil costs. The payback for the initial cost of the hardware and lubricant is less than 1 year, and subsequent years show lower operating costs [38].

Rotary Screw Compressors. Viscosity is the most critical lubricant requirement that must be met in the hydrocarbon gas rotary screw compressors. Viscosity may be lowered as the lubricant is diluted by the hydrocarbon gas in the compressor and oil separator. The final level of dilution is determined by the temperature and pressure in the separator, which is located on the discharge side of the compressor. Synthetic lubricants offer the advantage of very high viscosity and, in some cases, their resistance to dilution (lower solubility with hydrocarbon gases).

Polyalkylene glycols have reduced solubility with hydrocarbon gases. Different types of polyglycol can offer unique solubility characteristics, depending on their chemical structure. Polypropylene glycols are used with lighter hydrocarbons. Advantages such as higher volumetric efficiency and energy saving have been proven and are often the main criteria in their selection.

The inclusion of ethylene subunits in the polyglycol structure reduces hydrocarbon solubility. A copolymer of ethylene and propylene oxide will afford 10–20 wt % hydrocarbon solubility before the fluid is saturated. Water solubility is increased but controllable, as these fluids exhibit inverse water solubility at temperatures above 140–160°F (60–70°C). Solubility with water at lower temperatures as well as the use of specifically designed additives helps control corrosion, particularly where H_2S is present, by reducing free water on the metal surfaces. Essentially

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complete resistance to normal alkane dilution is possible with glycols based on ethylene oxide. Falling-ball viscosities carried out at 13,790 kPa (2000 psi) with a typical wellhead gas proved no loss in viscosity. Although these fluids are water soluble, lubricity is not reduced (four-ball tests) with up to 7% water in the lubricant [39]. Propane compressors may gain up to 18% improvement in volumetric efficiency with certain polyglycols [25].

Polyalphaolefins also show efficiency improvements. A methane gas compression application at a cogeneration plant showed a 2% increase in volumetric efficiency, without increased power consumption [39]. The compressor was equipped with a slide valve allowing it to run in an unloaded mode when demand was less than output capacity. With the synthetic lubricant, less power was used to drive the compressor, with more frequent operation in the unloaded mode. The PAO was originally chosen for improved water separation and low temperature fluidity, since the oil reservoir was located outdoors.

Reactive Gases. The use of "nonlubricated" compressors is common in the chemical industry. There may still be some chance of the gas contacting the lubricant (e.g., a seal leak). Each type of synthetic lubricant has a unique chemical functionality. This feature provides the opportunity to select a lubricant that will not chemically react with the gas. This property has led to the use of selected synthetics in lubricated compressors of reactive gases. In some cases the lubricant must provide a barrier to corrosive attack on the compressor materials. The impact of the lubricant on the particular chemical process (e.g., catalyst interaction) must also be considered. A general overview of the use of synthetic lubricants with reactive gases comprises the following points:

1. Oxygen compressors are usually the nonlubricated type. Highly fluorinated lubricants such as perfluoroethers are used.

2. Chlorine and hydrogen chloride compressors are usually nonlubricated types with halogenated lubricants used to lubricate mechanical parts. The lubricants are either the fluorinated (e.g, perfluoroethers or fluorosilicones) or the chlorofluorocarbon lubricants.

Some silicones have excellent chemical stability and protect metal surfaces from chemical corrosion. These have been combined with PAOs and/or severely hydrotreated hydrocarbons to provide the same metal protection obtained with the more expensive all-silicone fluids [25,40]. These silicone blends are effective in many process gas applications involving chlorosilanes, methyl chloride, hydrogen chloride, and other chlorinated compounds. Applications involving vent gases (off gases) can contain water and can be extremely corrosive. Successful operation is achieved at temperatures above the dew point of water and purging with a dry, inert gas upon shutdown [39].

3. Hydrogen sulfide, nitrous oxide, and sulfur dioxide all require lubricants that are dry. The later two are soluble in mineral oil and therefore reduce its viscosity. PAOs have a low tendency to absorb moisture, are available in high viscosity grades, and are suitable for these applications. The blended silicone described above has also been used for its additional corrosion protection.

4. Ammonia compressors typically use hydrocarbon lubricants. Hydrotreated mineral oils give extended life compared to naphthenic oil. PAOs and polyglycols are also used is some applications. Ester lubricants cannot be used because they react with the ammonia [41].

Inert Gases. Inert gases are classified as such because they are typically chemically unreactive and do not lead to general lubrication problems. Only highly purified mineral oils are used, since polar contaminants lead to general lubrication problems. Synthetics are preferred for improved stability and for prevention of catalyst poisoning. Additives must also be carefully evaluated for similar reasons. The use of rotary screw compressors with oil separators for these applications has resulted in the increased use of synthetics with low volatility. This helps reduce

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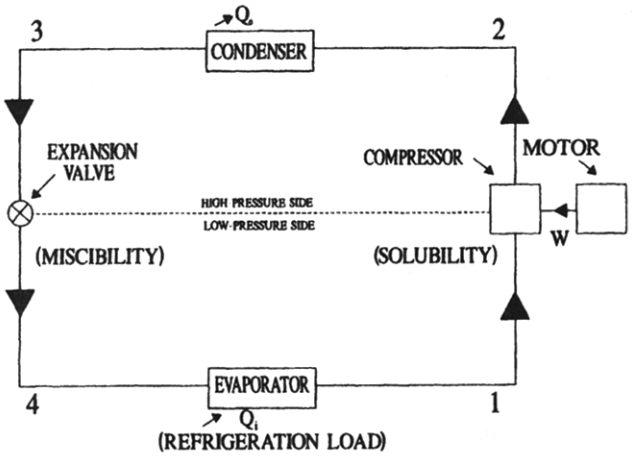

Figure 4 Refrigeration cycle.

contamination of the gas. Food-grade PAOs are used in carbon dioxide (CO_2) compressors, where the gas is later used in food products.

Polyglycols are commonly used in both hydrogen and helium applications. Polyglycols of the oxyethylene/oxypropylene copolymer types have shown good lubricity with reciprocating compressor polytetrafluoroethylene (PTFE) packings and compression rings in hydrogen applications and are compatible with plant processes. PAOs have replaced polyglycols in many hydrogen rotary screw compressor applications for cost reasons as well as for their compatibility with equipment and processes.

3. Refrigeration

The use of synthetic lubricants in refrigeration compressors has changed dramatically over the past 5 years. The main driver of this change has been the phaseout of chlorofluorocarbon (CFC) refrigerants, which led to the development of alternate refrigerants [42,43] with properties that preclude the use of traditional mineral oils (see below). The choice of refrigerant will influence the compressor system design and the characteristics required of the lubricant. Centrifugal compressors present a simple problem. There is little contact between the refrigerant and the lubricant. The lubricant in these machines may be selected to prevent problems associated with seal leakage (lubricant into the system) or for equipment so designed that the refrigerant has contact with the oil reservoir. Reciprocating and rotary (screw, scroll, and vane) compressors present a more complicated situation because there is significant interaction between the refrigerant and the lubricant [44].

Refrigeration lubricants may be required to provide many years of service without makeup and with a minimum of maintenance. Final compression temperatures may reach 320°F (160°C) for some applications, and unsuitable oils may form carbonaceous deposits. In the special case of hermetic compressors, the motor materials must not be adversely affected by the lubricant/refrigerant mixture or by-products from its deterioration. This application requires a lubricant that has excellent thermal and chemical stability and produces a minimum of deposits.

The Refrigeration Process. Figure 4 shows a simplified diagram of the refrigeration process. A liquid refrigerant vaporizes in the evaporator to provide the required cooling. The vapors then proceed to the compressor, where they are compressed to condensation pressure. In the con-

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denser, a cooling medium such as water or air is used to condense the superheated gas to a liquid. The liquid refrigerant then passes through an expansion valve (to reduce pressure) and is returned to the evaporator, where the cycle starts again.

The lubricant in compression refrigeration systems influences the operation and efficiency of the entire system [45]. Some lubricant is carried out of the compressor and into the system. The interactions of the refrigerant/lubricant pair will impact the return of this oil to the compressor. The lubricant must act as a compression sealing aid and reduce wear and friction in the compressor without adversely affecting the operation of the filter dryers, condenser, expansion valve, or evaporator. The lubricant must also be compatible with the materials of construction used in the entire system. The behavior of the oil/refrigerant pair is of major importance.

The solubility of the refrigerant gas in the lubricant impacts compressor performance, and the miscibility of the liquid refrigerant with the lubricant affects system performance. Dissolved gas in the lubricant reduces its viscosity. This can lead to excessive wear and inefficient compression. Miscibility is important for design of components and piping to allow uniform oil movement through the system and back to the compressor. Heat transfer problems are more significant in systems where the oil is immiscible or partly miscible with the refrigerant. The lubricant has more effect on the performance of a screw compressor than is the case with a reciprocating compressor, primarily because of differences in the design of the two oil systems. The screw compressor injects oil at discharge pressure into the compression chamber. This oil is then removed from the compressed gas by the use of an oil separator and sump situated on the high pressure side of the system. The screw compressor needs a lubricant with limited solubility of the refrigerant gas at discharge conditions (at the oil separator) to achieve high performance. Limited solubility will reduce or eliminate bypass of refrigerant from discharge to suction or to a lower situated thread. External bypass due to the refrigerant circulating with the oil is also reduced, leading to both high volumetric efficiency and low torque. Most lubricants with low refrigerant solubility also have low miscibility. In some cases a synthetic lubricant can meet the requirement of low solubility while maintaining good miscibility. This combined with low volatility reduces oil in the system and improves heat transfer [46].

Synthetics Used in Refrigeration. Synthetic lubricants offer a wide range of properties and the opportunity to customize a lubricant for a particular refrigeration system. They have been considered for refrigeration applications since 1929 [47] and have continued to show improvements in performance properties compared to mineral oils [48]. Properties of synthetic base stocks as they relate to refrigerant compression appear in Table 4. Of particular interest are the miscibilities of these fluids with various refrigerants exemplified in Figure 5. Typical applications appear in Table 5.

Polyalphaolefins. PAOs have been extensively used in refrigeration compressor applications because of their high viscosity index, fluidity at low temperatures, and excellent thermal and chemical stability.

The PAOs have good miscibility with R-12. Superior chemical and thermal stability have reduced the risk of carbonizing at high temperatures in heat pumps with R-12 and R-l14 [25,49]. Superior adiabatic efficiency (3–10%) is achieved in rotary screw compressors using these refrigerants with PAO compared to naphthenic refrigeration oils. This efficiency improvement is largely attributed to the higher viscosity of the PAOs at higher temperatures in the presence of the refrigerant. Superior performance and reliability have been achieved in reciprocating, twin-screw, and single-screw compressors [50].

Lower evaporator temperatures are permissible with PAOs than with mineral oils because PAOs are wax-free and have good low temperature fluidity. Low temperature fluidity is the major reason PAOs have been used in the United States for relatively insoluble refrigerants

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Table 4 Properties of Synthetic Refrigeration Lubricants.[a]

Properties	Synthetic hydrocarbons		Polyalkylene glycol	Esters		
	PAO	Alkylbenzene		Dibasic	Polyol	Silicate
Chemical stability	E	VG	G	G[b]	G[b]	G[c]
Thermal stability	VG	VG	G[d]	G	VG[e]	G
Miscibility (polar refrigerant)	P	VG	E	VG	E	E
Volatility	E	G	G	VG	E	VG
Low temperature	VG	G	G	VG	VG	VG
Viscosity temperature	VG	F	E	G	VG	VG
Water adsorption	E	G	P	F	F	F
Mineral oil compatibility	E	E	P	VG	G	P

[a] P, poor; F, fair; G, good; VG, very good; E, excellent.
[b] Additives may be required; reacts with ammonia (R-717).
[c] Hydrolyzes to form gels and solids.
[d] Decomposes at 500°F; additives may be required.
[e] Additives required above 200°C.

such as R-13 and R-503. The lubricant viscosity, ISO 15 or 32, is selected by considering operating viscosity in the compressor as well as low temperature fluidity below –73°C (–100°F) in the direct expansion dry-type evaporator system [51].

PAO applications with R-22 are limited, by low miscibility, to systems that limit the amount of the oil leaving the compressor. Evaporators of the dry expansion type are used (similar to R-13 applications), or flooded evaporators with oil-skimming devices.

PAOs with low volatility have been used in very low temperature [–118°C (–180°F)] ethylene systems. Separators can effectively control the amount of lubricant in the low tempera-

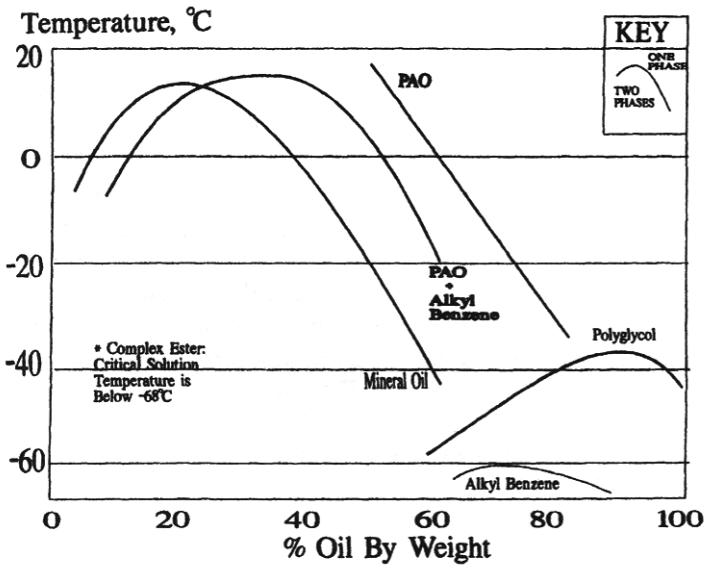

Figure 5 Miscibility characteristics for various fluids with HCFC-22.

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Table 5 Typical Applications for Refrigeration Lubricants

Refrigerant	Synthetic product
Chlorofluorocarbons (CFC)	Poly(α-olefins)
Hydrofluorochlorocarbons (HCFC)	Alkylbenzenes
	Complex esters
Highly fluorinated HCFC	Polyol esters
	Polyalkyene glycols
Hydrofluorocarbons (HFC)	Polyalkylene glycols
	Polyol esters
	Other esters
Ammonia	Poly(α-olefins)
	Hydrotreated ''semisynthetic''
Propane/hydrocarbons	Polyalkylene glycols
	Poly(α-olefins)
	Esters

ture side of the system. Careful selection of oil viscosity provides sufficient lubricant film to lubricate compressor components in the presence of the gas. The small amount of miscible lubricant is diluted in the evaporator and can be easily returned. Problems of wax or viscous liquid formation, as found with some mineral oils, are not encountered.

PAOs and "semisynthetic" high viscosity index (HVI) hydrotreated isoparaffinic mineral oils have been found to provide several performance advantages in ammonia systems [52]. Better thermal and chemical stability with ammonia results in reduced sludge and varnish and has resulted in extended drain intervals [53]. Lower solubility helps improve lubrication and reduces foaming. Lower volatility reduces oil consumption and improves heat transfer by limiting the amount of oil on heat exchanger tubing. The excellent low temperature fluidity and high viscosity index of the PAO fluids allows for evaporator temperatures below –46°C (–50°F) and, at the same time, provides sufficient viscosity for higher compressor operating temperatures. Good low temperature fluidity facilitates oil removal in most systems.

PAOs have seen only limited use in hydrofluorocarbon (HFC) applications because they are immiscible with these refrigerants. They are being used in extremely low temperature applications where their low temperature fluidity affords sufficient oil return [54].

Alkylbenzenes. Alkylbenzene synthetic hydrocarbon oils have good chemical stability and good miscibility with R-22 and R-502. They have somewhat improved miscibility with more highly fluorinated chlorofluorocarbon and hydrochlorofluorocarbon (HCFC) refrigerants such as R-13 and R-503. Alkylbenzenes are relatively low in cost compared to synthetics of other types, hence are commonly used with these moderately polar refrigerants.

The improved miscibility of the alkylbenzenes has led to their use with more environmentally safe HCFCs such as R-124 [55] and blends of HCFCs with hydrofluorocarbons (HFC) [56]. The use of alkylbenzenes with R-134a in rotary compressors has been evaluated, as well [57].

Alkylbenzenes are commercially available in ISO viscosity grades as high as 68 or 100. This has restricted their use where the solubility/viscosity relationships indicate a chance of overdilution. Compressors with oil reservoirs on the high pressure side, such as rotary screw types, are a particular concern. The viscosity–temperature relationship of the oil may be improved by increasing the carbon number of alkyl chains, at the expense of reduced miscibility. Formulations comprising blends of alkylbenzene with mineral oils or with a PAO may overcome

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these deficiencies. Private reports indicated that blends with PAO may separate in the liquid refrigerant in the evaporator [51].

Polyglycols. Polyalkylene glycols (PAG) have excellent miscibility with polar refrigerants, good lubricity, and good low temperature fluidity. Major drawbacks include their tendency to adsorb water, as well as low compatibility with mineral oils and the requirement of additives for good chemical and thermal stability. New developments with structural changes show promise in overcoming these deficiencies.

Polypropylene glycols have been used in R-12 heat pump applications in rotary screw compressors [47,58]. The PAGs have excellent viscosity temperature characteristics and reduced solubility with R-12. Efficiencies achieved were similar to those with PAO. The PAGs have also been used with R-22. When carefully selected, these oils have complete miscibility to temperatures below –73°C (–100°F), even at concentrations over 50% by weight with R-22. Higher viscosity grade PAG fluids have low miscibility with some highly fluorinated CFCs such as R-13 (chlorotrifluoromethane).

Polyalkylene glycols are miscible with hydrofluorocarbons such as HFC-134a and also with blends of HFC and HCFCs. This has resulted in their initial use with HFC-134a in automotive air conditioners [59–61] and rotary screw compressors [46,60]. Increasing the viscosity of polyglycols reduces miscibility, especially at higher temperatures. There have been some lubricity problems with these highly fluorinated refrigerants, particularly with higher loads in reciprocating-type compressors and with aluminum surfaces. Problems associated with water and materials compatibility have limited their use in small hermetic machines. “Modified” polyglycols have provided somewhat better performance [53,62].

Rotary screw compressors have shown improvements in volumetric efficiency (12%), refrigeration capacity (121%), and coefficient of performance (112%) in constant pressure ratio comparisons with CFC-12 [46,63]. The CFC-12 data were obtained using PAO of an equivalent viscosity (at compressor discharge temperature) as the lubricant. The polyglycol has excellent miscibility with R-134a at condenser and evaporator conditions but becomes less soluble within the compressor rotor bores. High viscosity during the compression cycle results in more efficient sealing between the rotors and between rotor and compression cylinder walls.

The polyglycols are used with hydrocarbon refrigerants for the properties described in the hydrocarbon gas section above. Because of their higher density, these lubricants are easily drained from the bottom of evaporators.

Specially designed polyglycols are also used in ammonia systems. Their structure is modified to provide partial [64] to complete [65] miscibility. The use of lubricants of these types improves system efficiency, particularly when DX-type evaporators are used.

Diesters. Diesters have been recognized for their potential in R-22 applications, since they are widely available and have excellent miscibility. Major problems may exist with these materials owing to poor stability with R-22 and a significant effect on the swelling of many elastomers [47]. An additional restriction for the use of these fluids in rotary screw compressors with R-22 is their limited range of viscosity grades (up to ISO 100).

Neopentyl Polyol Esters. Neopentyl esters (POE) were reported for use in low temperature [–80°C (–112°F) evaporator temperature] R-22 systems as long ago as 1968 [47,66]. Their polar nature causes these products to tend to absorb more moisture than mineral oils. Additives may be used to enhance the performance of these lubricants [67].

Lower viscosity grades of neopentyl esters, to 32 ISO, are miscible with the more polar refrigerant such as HFC-134a [68]. Higher viscosity polyol esters with selected chemical structures have been described for HFC-134a [69,70]. Because of the variety of polyols and acids available, lubricant suppliers are able to provide equiviscous fluids with different miscibility characteristics. This can lead to optimized compressor and system performance, as exemplified

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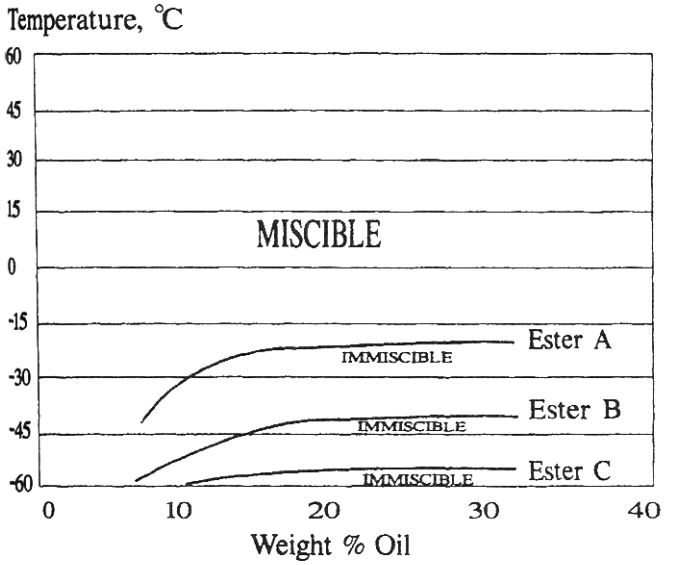

Figure 6 Miscibility of various ISO 32 polyol esters with HFC-134a.

in Fig. 6 [71]. Considerable additional development of POEs for use of HFC refrigerants has occurred over the last 7 years. Leading references are available [72,73].

High viscosity (ISO 100–320) complex esters were found to improve adiabatic and volumetric efficiencies in twin-screw compressors using HCFC-22 [74]. These oils were developed to have moderate to low dilution effects due to solubility while maintaining good miscibility. Their good miscibility (to below –90°F) has also led to their use in low temperature applications.

Silicate Esters. Silicate esters have been used at very low temperatures (with good miscibility) with highly fluorinated CFC refrigerants such as R-13. Problems have been reported that are associated with hydrolytic stability and the formation of varnishes or solids [75]. Different structures may solve these problems [47].

Phosphate Esters. Phosphate esters, such as tricresyl phosphate, are used as lubricity additives. They are no longer used as primary lubricants for refrigeration because viscosity–temperature relationships were poor and acids tended to form at higher temperatures[47],

Fluorinated Lubricants. Fluorinated lubricants such as perfluoroethers and fluorosilicone fluids are extremely miscible with nearly all halocarbon refrigerants. Their high cost has been a limiting factor for use in refrigeration compressors.

Fluorosilicone fluids are extremely miscible with HFC-134a. In compressor tests with 100 ISO fluorosilicone lubricants in automotive air-conditioning applications, there were bearing failures with aluminum components [76].

There has been recent interest in the partial fluorination of at least one alkyl end cap of polyglycols to improve their miscibility with HFC-134a [77]. Another approach has been to blend a chlorotrifluoroethylene polymer with polyglycols [78]. Either method is said to result in miscibility with HFC-134a throughout the operating range for air-conditioning applications.

III. VACUUM PUMPS

The same oils used for air compressors are suitable for most industrial vacuum pump applications. Synthetic oils with lower vapor pressures are used to achieve higher levels of vacuum

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without requiring substantial increase in viscosity. These oils include the esters and PAOs described earlier. Other types of synthetic fluid are used for their chemical compatibility with the gases being pumped. Diffusion pumps require lubricants that have undergone molecular distillation for ultrahigh vacuum.

Halogenated lubricants are used for their high chemical resistance to acids, alkalies, and corrosive gases, and their nonmiscibility with many common solvents. Perfluoroethers and chlorofluorocarbons are used extensively for plasma etching in industries such as semiconductor manufacturing and for producing aluminum chloride. The perfluoroethers can be used with pure oxygen and resists polymerization or the formation of nonvolatile residues when subjected to electron bombardment in sputter ion pump applications [79]. The perfluoroethers can break down in the presence of certain Lewis acids at temperatures above 210°F (100°C) to form toxic fragments [80].

Polyphenyl ethers and alkyl silicones have been used for high vacuum applications because they are thermally and chemically stable [81]. Fluorosilicones have better chemical stability.

IV. LIQUID PUMPS

The use of synthetic lubricants for pump applications is limited to applications either requiring compatibility with the material being pumped or having temperature requirements. The latter category includes high temperature applications where mineral oils may break down and applications where improved heat transfer properties of selected synthetics help remove heat. A few examples of the variety of applications for these lubricants follow.

The superior lubricity of some synthetic fluids provides better lubrication to seals and packings. One example is the reciprocating pump. The biggest maintenance problem with these pumps is the packing. There are many causes of short packing life, and one is lack of lubrication. Mineral oils with tallow additives have been used to provide tenacity for the plunger surface to improve the lubricant film between plunger and packing. It was shown earlier that polyglycols, silicones, and halogenated lubricants provide the same type of action in the presence of hydrocarbons that would wash away the tallow. Other synthetics are selected to resist washing away by the specific material being pumped.

Centrifugal pumps are widely used in the chemical industry. Fluorosilicone lubricants have been applied successfully on several seal arrangements to eliminate product leakage and extend seal life. These lubricants are resistant to temperature as high as 500°F, and to many chemicals and solvents that attack mineral oils (however, they are not suitable with ketones) [82].

Mineral oils and greases may break down at temperatures as low as 250°F (120°C), causing further temperature increases. Friction with packings rubbing on the shaft can easily generate these temperatures. The chemical being pumped is often at temperatures between 300 and 700°F (150 and 370°C). One method of heat removal is to use a double inside mechanical seal with a thermal convection lube system, a setup that normally requires very little attention. A molecular film of lube is maintained on the seal faces to provide lubrication. A low viscosity PAO has been used as the sealing and lubricating fluid. The fluid heats up in the pump stuffing box, rises, flows back to the supply tank, and is replaced by cool fluid from the supply tank. This is a thermal convection circulation system. A thin fluid is used for good circulation and to prevent openings in the seal faces.

Diaphragm pumps have been used for paint applications in the food industry. The fluid in one of these applications lubricates a reciprocating pump, which provides the pulsating action and acts against the diaphragm. There is the possibility that the diaphragm will develop a leak that remains unnoticed for some time. Synthetic fluids provide a broad enough selection to ensure that the fluid is compatible with the paint and also is “food grade.”

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A final example is the use of phosphate esters as lubricants for water reactor coolant pump motors. Fires had occurred when the oils used to lubricate primary system pump motors leaked onto hot primary piping. The oil is pressurized in the oil lift, so if a leak occurs, oil is sprayed on surrounding pipes. Several lubricants were tested for the required fire-resistant properties and adequate stability, including radiation resistance. These included mineral oils, diesters, methylalkyl silicones, and phosphate esters. It was found that mineral oils soaked in pipe insulation and maintained at temperatures above 375°F (190°C) eventually undergo exotherms to temperatures as high as 580°F (305°C). Storage temperatures for this type of exotherm to occur for other fluids were as follows: diester, 425°F (218°C), silicone, 400°F (204°C), and phosphate ester, 575–625°F (301–329°C). The temperature at which exotherms occurred was higher than the 550°F (288°C) operating temperature for the reactor's coolant pumps [83].

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